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## The planetary nebula Abell 48 and its [WN4] central star

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**Abstract.** We have conducted a multi-wavelength study of the planetary nebula Abell 48 and give a revised classification of its nucleus as a hydrogen-deficient star of type [WN4]. The surrounding nebula has a morphology typical of PNe and importantly, is not enriched in nitrogen, and thus not the ‘peeled atmosphere’ of a massive star. Indeed, no WN4 star is known to be surrounded by such a compact nebula. The ionized mass of the nebula is also a powerful discriminant between the low-mass PN and high-mass WR ejecta interpretations. The ionized mass would be impossibly high if a distance corresponding to a Pop I star was adopted, but at a distance of 2 kpc, the mass is quite typical of moderately evolved PNe. At this distance, the ionizing star then has a luminosity of  $\sim 5000 L_{\odot}$ , again rather typical for a PN central star. We give a brief discussion of the implications of this discovery for the late-stage evolution of intermediate-mass stars.

### 1. Introduction

Planetary nebulae (PNe) are the short-lived shrouds of ionized gas ejected from AGB stars. However, recent discoveries are showing that the diversity of evolutionary pathways leading to PN formation is greater than previously believed (Werner & Herwig 2006; Frew et al. 2010; Frew & Parker 2012; Todt et al. 2012). In the course of a spectroscopic survey of their central stars (CSPNe), we were struck by the unusual nature of the ionizing star of Abell 48. Depew et al. (2011) gave a preliminary classification of its CSPN as [WN] or [WN/C], but since the important C IV  $\lambda 5806$  doublet was unobserved, a more precise classification could not be given at that time. Independently, Wachter et al. (2010) classified the central source as a massive WN6 star, in contrast to its previous long association as a PN. This uncertainty led us to more closely investigate this interesting object. We have therefore conducted a detailed multi-wavelength study of Abell 48 and its central star, which confirms its PN nature and the [WN] status of its CSPN, as described below.

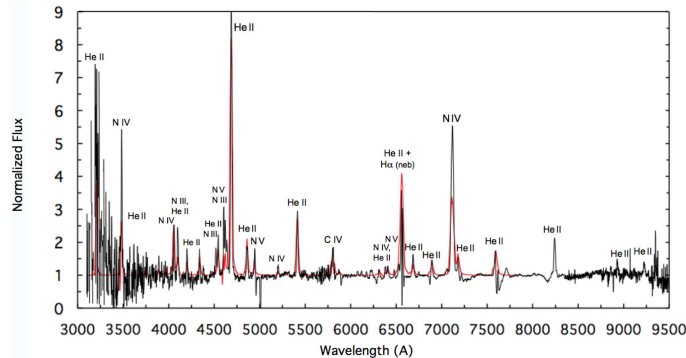


Figure 1. Normalized spectrum (black line) of the central star. Overplotted is model 10-13 (red line) from the Potsdam Wolf-Rayet grid (PoWR; Hamann & Gräfener 2004), which fits the relative strengths of the He lines well. The model parameters are  $T_{\text{eff}} = 71\text{kK}$  and  $\log R_i = 0.8$ , with the abundances set to He:C:N:O = 0.98: 1E-4: 0.015: 0.0. The relatively poor fit to the nitrogen lines suggests the adopted N abundance is at least a factor of two too low, or 3 to 4%.

## 2. Observations and Results

We combine the spectrum of the CSPN taken with the Hale 200-inch telescope (Wachter et al. 2010) with spectra of both the nebula and central star taken with the WiFeS IFU on the ANU 2.3-m telescope at Siding Spring Observatory in 2009 and 2010. An analysis of these spectra shows that the CSPN is helium-rich (Figure 1). Based on the presence of strong N IV lines and moderately strong N V lines at  $\lambda\lambda 4604, 4620$  relative to N III  $\lambda\lambda 4634, 4640$ , we classify it as [WN4] with an upper limit for hydrogen of 10%. We also retrieved archival multi-wavelength data via the CDS for the star and nebula. From the CSPN colours and nebular Balmer decrement, we determine  $E(B - V) = 2.0$ . Adopting this reddening and the integrated nebular flux from Frew et al. (2012),  $\log F(\text{H}\alpha) = -11.5$ , we estimate a distance of 2.0 kpc, giving the CSPN a luminosity of  $\sim 5000 L_{\odot}$ .

## 3. The CSPN of Abell 48: unambiguously not a massive star

Miszalski et al. (2012) dismissed Abell 48 as a massive star, but gave no justification for this conclusion. Based on an objective assessment of all currently available multi-wavelength data, we discount a Population I interpretation, and conclude that this is a bona fide PN. Critically, the surrounding nebula is not enriched in nitrogen, indicating it is not the ‘peeled atmosphere’ of a massive star. Indeed, no WN4 star is known to be surrounded by such a compact nebula. Furthermore, given the known reddening and adopting an appropriate absolute magnitude from Crowther et al. (2006), it would be at a distance of  $>11$  kpc if it was truly a massive star. This location is on the far side of the Galactic bar, and cannot be reconciled with the observed reddening, a point alluded to by Wachter et al. (2010). The nebular ionized mass (determined from the distance, nebular diameter,  $\text{H}\alpha$  flux, and reddening) would also be impossibly high, around  $40 M_{\odot}$ . In addition, the morphology of the nebula and its location in the line- $\text{H}\alpha/[\text{NII}]$  vs  $\text{H}\alpha/[\text{SII}]$  diagnostic plot (Fig. 2), indicate that Abell 48 is a bona fide PN.

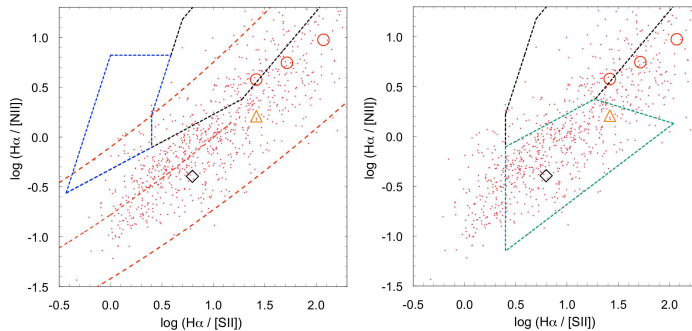


Figure 2. Diagnostic plots updated from (Frew et al. 2010). Individual PNe are shown as small dots and fields showing HII regions, LBV/WR ejecta, SNRs and PNe are marked; note the considerable overlap between them. The red circles show Abell 48, IC 4663, and PB 8 (refer to the text), which all plot squarely in the PN domain, while the triangle is LMC N66. On the other hand, the ring nebula around the WN7b star PMR 5 (black diamond) is strongly nitrogen enriched from CNO cycling, and plots in the area which includes both LBV/WNL ejecta and Type I PNe.

While any identification as a massive star is highly problematic, we emphasize that *there are no observables in conflict with the PN interpretation.*

#### 4. Related Objects

Unlike the peculiar nebula LMC N66, which may be a nebula around an accreting binary star (Hamann et al. 2003), we find no evidence of spectroscopic or photometric variability in the CSPN of Abell 48. The atmospheric composition is also different to the [WN/WC] nucleus of PB 8 (Todt et al. 2010a; Miller Bertolami et al. 2011), illustrating the diversity of compositions seen in post-AGB stars. After we commenced this study, Miszalski et al. (2012) discovered a hot, helium-rich [WN3] CSPN in IC 4663, with  $T_{\text{eff}} = 140 \text{ kK}$  and an estimated luminosity of  $4000 L_{\odot}$ , quite typical of a CSPN nearing the knee in its evolutionary track. Incidentally, we also reclassified PMR 5 (Morgan et al. 2003; Todt et al. 2010b) on the basis of a deeper WiFeS spectrum, and revise its classification to WN7b. We also show that the surrounding nebula is composed of strongly CNO-processed material ejected from a massive star at a distance of about 3.5 kpc. A fuller account will be published separately.

#### 5. Discussion and Future Work

The recent discovery of two helium-dominated Galactic [WN] CSPN by Depew et al. (2011, Abell 48) and Miszalski et al. (2012, IC 4663) has confirmed that the diversity of post-AGB pathways is greater than previously thought. The [WN] stars are the progenitors of the O(He) stars (Rauch et al. 1994, 1998, 2006; Reindl et al. 2012; Miszalski et al. 2012), and will ultimately become DO white dwarfs as they fade and cool. However their immediate progenitors remain uncertain, but are possibly the R CrB stars (e.g. Rauch et al. 2008). There is an early suggestion that the scale height of

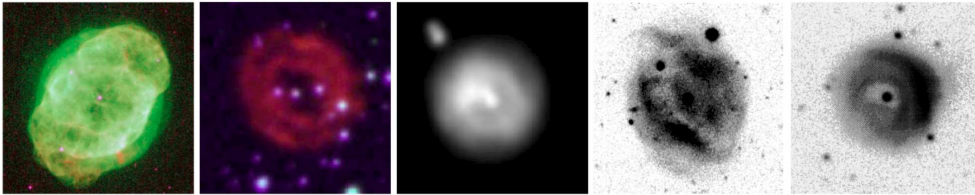


Figure 3. Image montage of IC 4663, Abell 48, PB 8, K 1-27, and LoTr 4 respectively (images from Hajian et al. 2007, Schwarz et al. 1992 and Rauch et al. 1996, 1998). The morphology of Abell 48 is quite similar to K 1-27 and LoTr4.

Galactic [WN/C] stars and their offspring, the O(He) stars, is larger than for the PN population as a whole (Frew & Parker 2012), which suggests that these objects may derive from lower-mass progenitor stars. To test this hypothesis we are obtaining new observations of additional candidate [WN] or [WN/C] stars (e.g. Parker & Morgan 2003; Todt et al. 2012). Clearly larger samples are required before definite conclusions can be made on their origin, so much more work needs to be done.

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